Practical Power Cable Ampacity Analysis

An Online Continuing Education Course for Engineers

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Practical Power Cable Ampacity Analysis

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Introduction

Cable network usually forms a backbone of the power system. Therefore, complete analysis of the power systems includes detailed analyses of the cable network, especially assessment of the cable ampacities. This assessment is necessary since cable current carrying capacity can depend on the number of factors that are predominantly determined by actual conditions of use. Cable current carrying capability is defined as “the current in amperes a conductor can carry continuously under the conditions of use (conditions of the surrounding medium in which the cables are installed) without exceeding its temperature rating limit.”

Therefore, a cable current carrying capacity assessment is the calculation of the temperature increment of the conductors in an underground cable system under steady-state loading conditions.

The aim of this course is to acquaint the reader with basic numerical methods and methodology that is used in cable current sizing and calculations. Also use of computer software systems in the solution of cable ampacity problems with emphasis on underground installations is elaborated.

The ability of an underground cable conductor to conduct current depends on a number of factors. The most important factors that are the biggest concerns to the designers of electrical transmission and distribution systems are the following:

- Thermal details of the surrounding medium
- Ambient temperature
- Heat generated by adjacent conductors
- Heat generated by the conductor due to its own losses

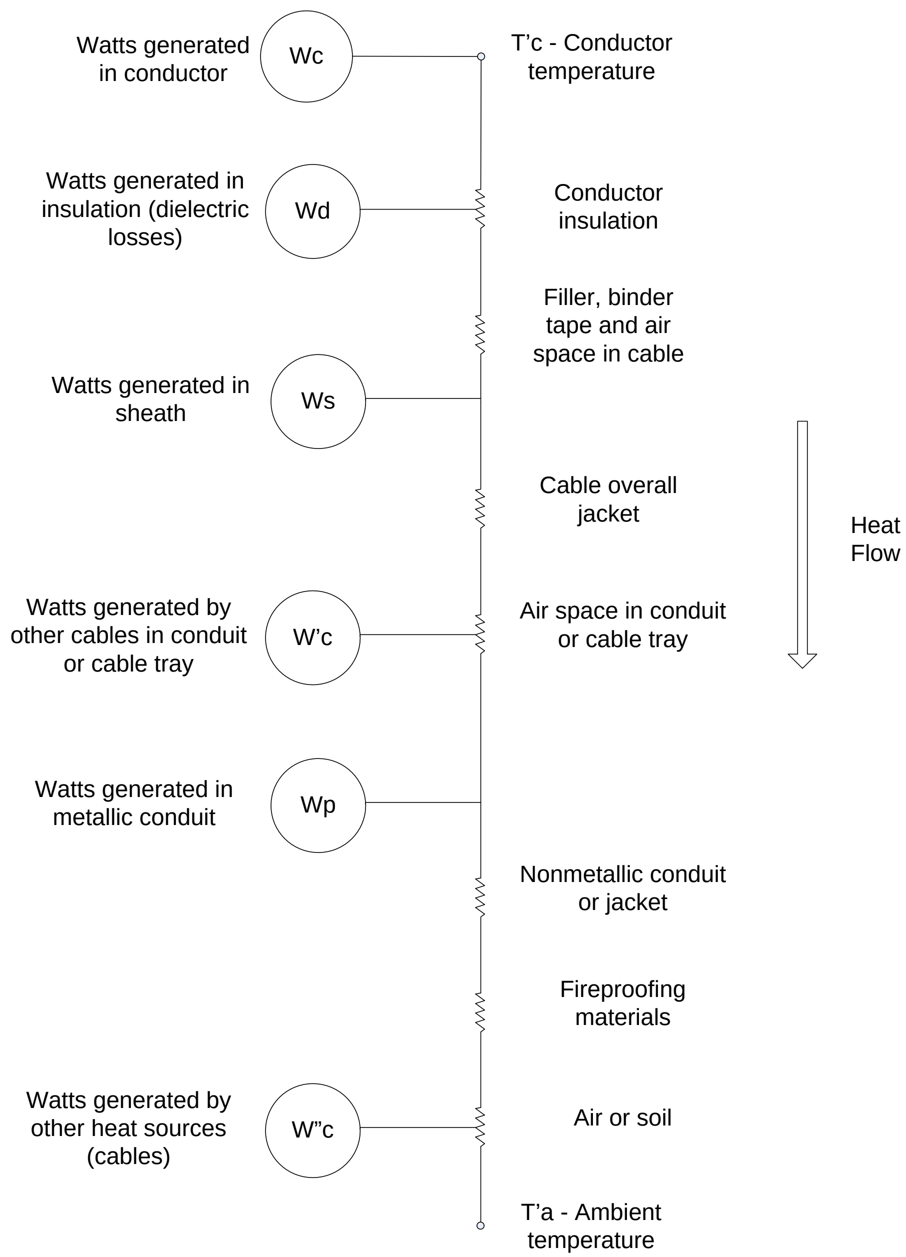
Methodology for calculation of the cable ampacities is described in National Electrical Code ® (NEC®) which uses Neher-McGrath method for calculation of the conductor ampacities. Conductor ampacity is presented in the tables along with factors that are applicable for different laying formations. Alternative approach to the one presented in the NEC® is the use of equations for determining cable current carrying rating. This approach is described in NFPA 70-1996. Underground cable current capacity rating depends on various factors and they are quantified through coefficients presented in the factor tables. These factors are generated using Neher-McGrath method. Since the ampacity tables were developed for some specific site conditions, they cannot be uniformly applied for all possible cases, making problem of cable ampacity calculation even more challenging. In principle, factor tables can be used to initially size the cable and to provide close and approximate ampacities. However, the final cable ampacity may be different from the value obtained using coefficients from the factor tables. These preliminary cable sizes can be further used as a basis for more accurate assessment that will consider very specific details such as soil temperature distribution, final cable arrangement, transposition etc.

Assessment of the Heat Flow in the Underground Cable Systems

Underground cable sizing is one of the most important concerns when designing distribution and transmission systems. Once the load has been sized and confirmed, cable system must be designed in a way to transfer required power from the generation to the end user. The total number of underground cable circuits, their size, the method of laying, crossing with other utilities such as roads, telecommunication, and gas or water network are of crucial importance when determining design of the cable systems. In addition, underground cable circuits must be sized adequately to carry the required load without overheating.

Heat is released from the conductor as it transmits electrical current. Cable type, its construction details and installation method determine how many elements of heat generation exist. These elements can be Joule losses (I^2R losses), sheath losses etc. Heath that is generated in these elements is transmitted through a series of thermal resistances to the surrounding environment. Cable operating temperature is directly related to the amount of heat generated and the value of the thermal resistances through which is flows. Basic heat transfer principles are discussed in subsequent sections but a detailed discussion of all the heat transfer particularities is well beyond the scope of this course.

Calculation of the temperature rise of the underground cable system consists of a series of thermal equivalents derived using Kirchoff's and Ohm's rules resulting in a relatively simple thermal circuit that is presented in the figure below.



Equivalent thermal circuit involves a number of parallel paths with heath entering at several different points. From the figure above it can be noted that the final conductor temperature will be determined by the differential across the series of thermal resistances as the heath flows to the ambient temperature T_a'.

Fundamental equation for determining ampacity of the cable systems in an underground duct follows the Neher-McGrath method and can be expressed as:

$$I = \left[\frac{T_c' - (T_a' + \Delta T_d + \Delta T_{int})}{R_{ac} \cdot R_{ca}'}\right]^{1/2} kA$$

Where:

T_c' is the allowable (maximum) conductor temperature (°C)

T_a' is ambient temperature of the soil (°C)

ΔT_d is the temperature rise of conductor caused by dielectric heating (°C)

ΔT_{int} is the temperature rise of conductor due to interference heating from cables in other ducts (°C). It has to be noted that simulations calculation of ampacity equations are required since the temperature rise, due to another conductor depends on the current through it.

R_{ac} is the AC current resistance of the conductor and includes skin, AC proximity and temperature effects (μΩ /ft)

R_{ca}' is the total thermal resistance from conductor to the surrounding soil taking into account load factor, shield/sheath losses, metallic conduit losses and the effect of multiple conductors in the same duct (thermal-Ω /ft, °C-ft/W).

All effects that cause underground cable conductor temperature rise except the conductor losses $I^2R_{ac}$are considered as adjustment to the basic thermal system.

In principle, the heath flow in watts is determined by the difference between two temperatures $(T_c' - T_a')$ which is divided by a separating thermal resistances. Analogy between this method and the basic equation for ampacity calculation can be made if both sides of the ampacity equation are squared and then multiplied by R_{ac}. The result is as follows:

$$I^2R_{ac} = \frac{T_c' - (T_a' + \Delta T_d + \Delta T_{int})}{R_{ca}'} \; W/ft$$

Even though understanding of the heat transfer concepts is not a prerequisite for calculation of the underground cable ampacities using computer programs, this knowledge and understanding can be helpful for understanding how real physical parameters affect cable current carrying capability. From the ampacity equation it can be concluded how lower ampacities are constitutional with the following:

- Smaller conductors (higher R_{ac})
- Higher ambient temperatures of the surrounding soil
- Lower operating temperatures of the conductor
- Deeper burial depths (higher R_{ca}')
- Smaller cable spacing (higher ΔT_{int})
- Higher thermal resistivity of soil, insulation, concrete, duct, etc. (higher R_{ca}')
- Cables that are located in inner, rather than outer, ducts (higher ΔT_{int})

Factors that also reduce underground cable ampacity but whose correlation to the cable ampacity equation is not apparent are:

- Higher insulation SIC and power factor (higher ΔT_d)
- Higher voltage (higher ΔT_d)
- Higher load factor (higher R_{ca})
- Lower shield / sheath resistance (higher R'_{ca})

Use of Computer Programs for Calculation of Underground Cable Ampacity

Software programs usually use Neher-McGrath method for calculation of the cable ampacity. They consider only temperature-limited, current-carrying capacity of cables. Calculation of the cable ampacity considers only power cables since control cables transmit very little current that has negligible effect to the overall temperature rise. Other important factors that need to be considered when selecting power cables are voltage drop, short circuit capability and future load growth.

Calculation of the underground cable ampacity is very complex process that requires analysis of multitude of different effects. In order to make calculations possible for a wide variety of cases, assumptions are made. Majority of these assumptions are developed by Neher and McGrath and they are widely accepted. There are also computer programs that base their assumptions on different methods but those are separately explained.

Basic steps that cable ampacity software tools use are discussed below. Described methodological procedure needs to be followed in order to obtain good and accurate results.

1. The very first step that needs to be taken when designing an underground cable system is to define which circuits needs to be routed through the duct bank. Attention needs to be paid to existing circuits as well as future circuits that may be additionally installed. Only power cables need to be considered in this assessment but space needs to be allowed for spare ducts or for control and instrumentation cables.

2. The cable duct needs to be designed considering connected circuits, cable conductor axial separation, space available for the bank and factors that affect cable ampacity. For example, power cables that are installed in the vicinity of other power cables of that are deeply buried often have greatly reduced current carrying capacity. Also decision regarding burring ducts or encasing them in the concrete need to be made. Also the size and type of ducts that need to be used should be decided. Lastly, a schematic drawing of the duct bank needs to be prepared indicating burial depths and axial spacing between cable conductors. Physical information of the duct installation needs to be compiled including thermal resistivity of the soil and concrete as well as ambient temperature of the soil. It is important to note that soil thermal resistivity and temperature at specific areas (e.g., desert, frequently flooded areas) may be higher than the typical values that are normally used.

3. Overall installation information about power cables need to be collected and collated. Some basic information can be taken from the predefined tables but certain data needs to be obtained from manufacturer's specifications. Construction and operational parameters that include conductor size, operating voltage, conductor material, temperature rating,

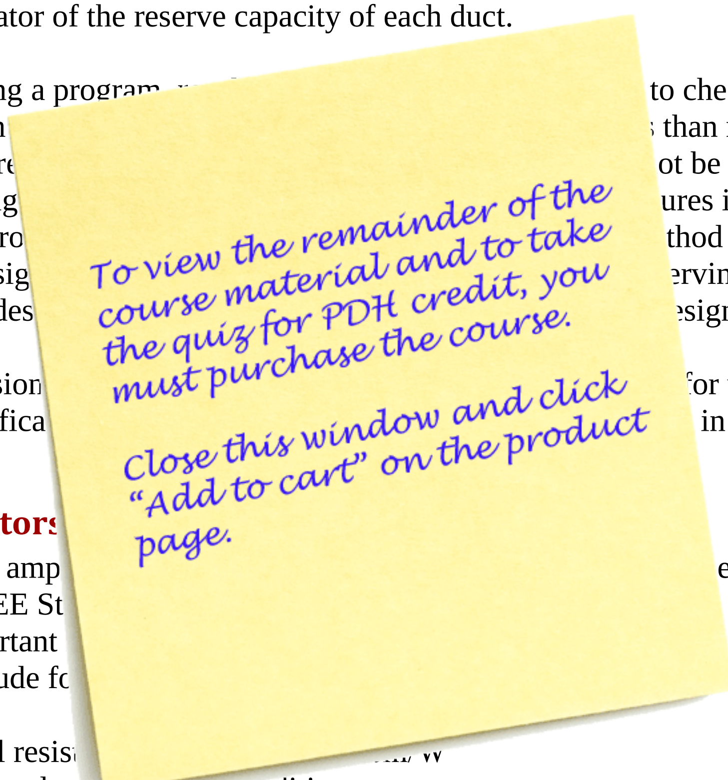
type of shield or sheath, jacket type, and insulation type need to be specified and considered.

4. Preliminary cable arrangement needs to be made based on predicted loads and load diversity factors. Circuits that are expected to transfer high current and those having high load factors should be positioned in outside ducts near the top of the bank to avoid use of larger conductors due to unnecessarily reduced ampacity. Normally, a good compromise between the best use of duct space and greatest ampacity is achieved by installing each three-phase circuit in a separate duct. However, single-conductor cables without shield may have greater current carrying capacity if each phase conductor is installed in a separate non-metallic duct. In the case that the load factor is not known, a conservative value of 100% can be used, meaning that circuit will always operate at peak load.

5. Presented steps can be used to initially size power cables based on the input factors such as soil thermal resistivity, cable grouping and ambient temperature. As soon as initial design is made, it can be further tuned and verified by entering the program data interactively into the computer software or preparing the batch program. Information that will be used for cable current carrying calculations need to consider the worst case scenario. If load currents are known they can be used to find the temperatures of cables within each duct. Calculations of the temperature are particularly useful if certain circuits are lightly loaded, while remaining circuits are heavily loaded and push ampacity limits. The load capacity of the greatly loaded cables would be decreased further if the lightly loaded cables were about to operate at rated temperature, as the underground cable ampacity calculation normally assumes. Calculations of the temperature can be used as a rough indicator of the reserve capacity of each duct.

6. After running a program, … to check if design currents are less than … than rated temperatures. If obtained re… ot be applied and used, various mitig… ures include increasing conductor cro… thod or changing the physical desig… rving their influence on the overall des… sign is achieved.

7. The conclusion… for use in controlling future modifica… in remaining, spare ducts).



Adjustment Factors

Underground cable amp… evant standards such as the NEC and IEEE St… conditions that were considered as important … ent. Site specific conditions can include fo…

- Soil thermal resis…
- Installation under a… condition